AD-754 335

PROPERTIES OF SURFACE SOILS IN THE WET SEASON

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Army Engineer Waterways Experiment Station
Vicksburg, Mississippi

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AD 754335

MISCELLANEOUS PAPER NO. 4-447

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ARMY-MRC VICKSBURG, MISS

Preface

This paper was submitted for Technical Division 1, "Soils Properties and Their Measurement," of the Fifth International Conference of the International Society of Soil Mechanics and Foundation Engineering held in Paris, France, July 1961. It is based on work sponsored by the Office, Chief of Engineers, and was approved by that office.

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Abstract

Results are summarized of tests of moisture content, density, and strength of surface soils at several hundred sites in humid-climate areas of the United States. A first-order approximation of values of these properties on the basis of soil texture is indicated by a graphic analysis.

Sommaire

Les auteurs présentent un résumé des résultats d'essais de teneur en eau, de densité et de résistance des sols de surface en plusieurs centièmes d'endroits dans des régions de l'Amérique du Nord ayant un climat humide. Une première approximation de valeurs de ces propriétés, basée sur la texture du sol, est indiquée par moyen d'une analyse graphique.

Introduction

This paper summarizes the results of in-situ tests performed at several hundred sites to determine certain properties in the surface foot of soil. Usually this top layer of soil is not considered in soil mechanics problems, particularly if it is soft, since it can be and generally is stripped and wasted. Thus the data presented herein, which not only deal with this commonly ignored layer but also were obtained in wet, soft soils, are somewhat unique. However, to engineers interested in soil trafficability,* data defining the properties of this layer are of paramount importance; they also may be of interest to civil and agricultural engineers who are concerned with surface soils.

The tests were performed over a number of years by U. S. Army Engineer Waterways Experiment Station personnel for a study of the trafficability of soils. The several hundred sites used represent a wide range of soil types in humid-climate areas of the United States. The tests consisted of determinations of moisture content, density, and strength, and were made when the soils were very wet but not frozen. Mean values and ranges of these properties for various soil types are shown, and an explanation of the variation in mean values in terms of soil texture is offered.

Only the soil layer from 6 to 12 in. below the surface was tested as this layer is the most important from a trafficability standpoint. No data were collected on clean sands and gravels in this study because such soils normally do not present trafficability problems.

* Trafficability is the ability of a soil to permit the movement of a vehicle. See "Trafficability of soils studies," G. B. Schoolcraft, W. K. Boyd, and C. R. Foster. Proceedings of the Second International Conference on Soil Mechanics and Foundation Engineering, 1948. Vol V, Rotterdam, June 21 to 30, 1948, pp 206-208.

Fine-grained soils (more than 50% of the material finer than 0.074 mm) are usually associated with the worst trafficability conditions, and most of the sites tested were in this class. However, the sites included many coarse-grained soils with significant proportions (usually more than 10%) of fine-grained materials. When wet, some of these soils also exhibit poor trafficability characteristics. Although the majority of the sites were located in humid-climate areas of the United States, some were located in the subhumid to semiarid western United States but were tested under very wet conditions. On a regional basis, the southeastern part of the United States is best represented by the data. All of the sites tested were level or nearly level.

Sites with water tables near the surface as well as sites with deep water tables are included. All sites had had a minimum of recent disturbance by man. They include unused land, forests, pastureland, and farmland not recently cultivated. The sites represent a variety of land forms of glacial-alluvial-, aeolian-, and residual-type origin. Rocky, stony, or mountain-type soils are not represented.

The principal factor influencing the strength of a given soil, especially a fine-grained one, is the amount of water it contains. When relatively dry, a soil is firm regardless of its type; when wet, the soil may be very weak. At the same specific moisture content one soil may be much stronger than another. Two soils of the same strength may have entirely different moisture contents. In any comparison of strengths of various soils, it is thus necessary that moisture conditions be on some common basis.

Trafficability studies performed at the Waterways Experiment

Station* have clearly demonstrated the feasibility of establishing one common moisture basis, called the field maximum moisture. The studies show that in a humid climate the 6- to 12-in. layer of a given fine-grained soil will attain a certain maximum moisture content early in the "wet" season and maintain this moisture content with very little deviation throughout the season. Once the field-maximum-moisture content is reached, additional rainfall will not materially increase the moisture content. The excess water will percolate downward through the 6- to 12-in. layer or run off the surface to drainageways. In humid regions, the field-maximum-moisture content generally is higher than the moisture content termed "field capacity" by agricultural scientists.** In humid regions, the wet season corresponds closely to winter, the season in which low temperatures and frequent cloud cover combine to reduce evaporation of moisture from the soil, in which dead or dormant vegetation no longer extracts moisture through transpiration, and frequent frontal-type rains replenish the slight losses that do occur. The 6- to 12-in. layer also may attain field-maximum-moisture content for short periods in any season of the year, but in drier seasons evapotranspiration quickly reduces the moisture content.

Many of the sites for which data appear in this paper were tested on a near-daily basis for several years, and the data are known to be representative of field-maximum-moisture conditions. The majority of the sites, however, were visited only a few times or once during the wet season. The

* Waterways Experiment Station Technical Memorandum No. 3-331, Forecasting Trafficability of Soils, Reports 1-5.

** Field capacity is the moisture content held in a soil with adequate opportunity for drainage after the excess gravitational water has drained away and after the rate of downward movement of water has materially decreased.

data for such sites are not as representative as the data for the sites visited daily since the visit might have been made following a period of little rain, or, in rarer instances, during or immediately following a rain. In the latter case, the moisture content measured might actually have been slightly higher than field-maximum-moisture content. The use of data from sites tested infrequently probably produces a bias toward lower moisture contents; however, the bias is not considered great.

Test Data

The variations measured in the soil properties are shown graphically in figures 1-5, grouped by both USCS and USDA soil types. The mid-point of each bar represents the arithmetical mean for all samples of the same soil type. The soil types have been arranged in numerical order of mean values. The length of each bar represents the mean value plus and minus one standard deviation. The number of samples for each soil type is shown at the top of the bar. The total number of samples considered for a given parameter is indicated on its particular series of histograms. The number of samples was not the same for each analysis because all five parameters were not always measured on all samples. Also, more samples are shown for USCS classifications than USDA classifications because the grain-size tests, to 0.002 mm, necessary for USDA classification were not performed in all cases.

Classification

Tests for grain-size distribution and Atterberg limits were performed on most of the soil samples collected in the general trafficability studies, and the samples were classified according to the Unified Soil

Classification System (USCS)* and the U. S. Department of Agriculture (USDA) textural classification system.** Table 1 compares the classifications by each system. As can be seen from the table, the fine-grained soils comprise the majority of the total. The predominant USCS type is CL; the predominant USDA type is SiL.

Moisture

Field-maximum-moisture contents are shown in figure 1. Attention is directed to the high values shown for the OH (USCS) soil type. The eight samples of this organic soil classified as silt loam (SiL) or loam (L) in USDA terms. When considered statistically with these more numerous soils, the high values of moisture content fell outside the range of data represented by plus one standard deviation.

Density

Mean values and ranges of density (defined as the dry unit weight of soil, and expressed in pounds per cubic foot) are plotted in figure 2. It is apparent that the soil type order is generally similar but not the same as that for increasing mean moisture-content values.

Strength

In the trafficability studies, in-situ strength is measured in terms of cone index. The cone index is the force required to move a right circular 30-degree cone of 1/2-sq-in. base area slowly through a plane in the soil. The force is expressed in pounds per square inch (of cone base). Cone index has been found to be roughly equivalent to the unconfined

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* Waterways Experiment Station Technical Memorandum No. 3-357, The Unified Soil Classification System. March 1953.

** Soil Survey Manual, U. S. Dept. of Agriculture Handbook No. 18. August 1951.

compressive strength in pounds per square inch multiplied by 5, and to the California Bearing Ratio* multiplied by 35 to 40.

Because the wet soils of greatest interest in trafficability studies generally lose a considerable proportion of their in-situ strength when remolded under the dynamic action of a column of vehicles traveling in the same path, an expedient test of the sensitivity of soils was devised. This test consists of measuring the cone index in a 7-in.-long, 2-in.-diameter sample of soil, contained in a steel cylinder, at 1-in. increments to a depth of 4 in., remolding the soil by application of 100 blows of a 2-1/2-lb hammer falling freely for 12 in., and then remeasuring the cone index in the same way. The index of sensitivity, called remolding index in trafficability studies, is computed by dividing the average value of cone index after remolding by the initial average value. It will be noted that remolding index is the inverse of sensitivity, i.e., sensitivity indexes are usually determined by dividing the unremolded strength by the remolded strength. The product of remolding index and in-situ cone index, termed rating cone index, closely approximates the effective strength of a soil under a moving vehicle (the remolded strength) and has been successfully correlated with vehicle performance.

Cone index values are shown in figure 3. Remolding index and rating cone index values are shown in figures 4 and 5, respectively.

Discussion

The plots (figures 1-5) point out the wide variations that occur in

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* "Development of CBR flexible pavement design method for airfields," A Symposium. ASCE Transactions, vol 115, 1950, p 453.

each of the parameters considered despite the fact that the measurements were made under common environmental conditions, i.e., when the soil moisture contents were at field maximum values, their wettest natural state. For example, field-maximum-moisture content (figure 1) varies from 4.5% (lower limit for SP-SM soils) to 99% (upper limit for OH soils). It is to be noted that while some similarity in soil type orders is apparent, the orders are not the same for all the parameters. It is further noted that ranges of values for some soil types completely encompass ranges for other soil types. For example, the moisture content for silt loam (SiL) soils ranges from 20 to 37%. This includes the range for clay loam (CL) (22 to 34), silty clay loam (SiCL) (24 to 33), silty clay (SiC) (27 to 37), and silt (Si) (29.5 to 34.5).

An attempt was made to determine whether a correlation existed between the values of each of the respective parameters and the soil texture by plotting the several hundred soils (in terms of per cent sand, silt, and clay) on a large USDA textural triangle and writing the values of the parameter at the plotted points. The result was a seemingly chaotic scatter of values, reflecting the differences in each of the respective parameters caused by topographic position, presence or absence of water table and impermeable layers, structure, vegetation, and the many other varying environmental factors besides texture which influence the moisture-retention capacity, density, and strength of soils. This plot is not shown in this paper. However, similar plots made for the mean values of the respective parameters displayed reasonable patterns of variation, despite the disparity in the number of samples comprising the means for the various soil types. In figure 6, mean values of moisture content, density,

cone index, remolding index, and rating cone index have been written at the centroids of the areas representing the several USDA soil types, and isograms drawn. The resulting patterns are discussed in the following paragraphs.

Moisture-content values are at a minimum in the sandy soils which are coarser, have lower void ratios and larger (noncapillary) pores, and are, therefore, better drained than silty and clayey soils. From the lower left-hand corner (100% sand), moisture content increases radially, i.e., with a decrease in sand content and a consequent increase in silt or clay content. The rate of increase of moisture is faster toward the clayey soils than toward the silts.

Density values are at a maximum in sandy soils. An interesting "ridge" of high density occurs in the well-graded soils, sandy clay loams, clay loams, and silty clay loams. As this ridge is followed from left to right, i.e., as sand content is decreased, density also decreases. If a departure from the ridge toward higher clay or silt contents is made, abrupt decreases in density follow, apparently because the soil becomes less well graded. Density decreases more rapidly toward clay than toward silt.

Cone index is at a minimum in loam where densities are comparatively low. A rapid increase in cone index occurs with an increase in sand content, and cone index reaches a maximum in the very sandy soils, where density values are comparatively high and moisture contents are low. Cone index appears to increase slowly with an increase in clay content, and then decrease. This corresponds to an increase followed by a decrease in density, and also corresponds to little change in moisture content followed

by slow increases in moisture content. Cone index also appears to increase from loam toward the silty soils, despite the fact that density decreases slowly and moisture increases slowly in this direction. This small increase in cone index cannot be satisfactorily explained in terms of moisture content and density changes and may, in fact, only reflect an erroneous value (140) in the loam soil.

Remolding index increases radially from a minimum in silt toward 100% sand and 100% clay. A value of 1.00 occurs in sandy loam, sandy clay, and perhaps again in soils with very high clay content. Although most discussions on sensitivity emphasize the high sensitivity of clay, in the trafficability studies inorganic clays have usually been found to be much more stable than silts. Values greater than 1.00, indicating a gain in soil strength through compaction, occur in the sandy soils area near the lower left-hand corner.

Rating cone index reflects the product of cone index and remolding index. Minimum values of rating cone index lie in the lower right-hand corner in silty soils and increase radially toward increasing sand contents and clay contents. The rate of increase toward sand is much faster than toward clay, and maximum values of rating cone index are found in the sandy soils.

Summary

In summary, moisture content, density, and strength indices (cone index, remolding index, and rating cone index) are seen to vary widely in surface soils even though these parameters were measured when all the soils were at similar field conditions, i.e., at field-maximum-moisture content.

When the soil types are arranged according to decreasing mean values of the several parameters (increasing for moisture content) a general similarity of the orders of arrangement may be noted, but the orders are not the same. However, when the mean values of the parameters are plotted on a soil textural background, the resultant patterns appear orderly and explainable in terms of porosity, grain sizes, and grain shape, functions of soil texture itself. The analysis provides a first-order approximation of the variation of the moisture content, density, and strength of surface soils at field maximum moisture on the basis of their textures.

Table 1

Number of USCS-USDA Soil Types Sampled

USDA Symbol	USCS Symbol: GM	GC	SP-SM	SM	SM-SC	SC	ML	CL-ML	MH	CL	CH	OL	OH	Pt	Total
S			9	34	1										44
LS				56		1									57
SL	1			85	17	28	40	9		18		5	4		207
SCL				3	1	7	2			15					28
SC						1				1					2
L	1	1					36	19	1	87	5	5	10		165
SiL							172	47	16	215	12	9	10		481
Si							10			1					11
CL							2		1	30	6		1		40
SiCL							1	1	1	51	20		2		76
SiC							1			5	15				21
C							1		4	5	25		3		38
Pt														6	6
Total	2	1	9	178	19	37	265	76	23	428	83	19	30	6	1176

USDA Soil Types

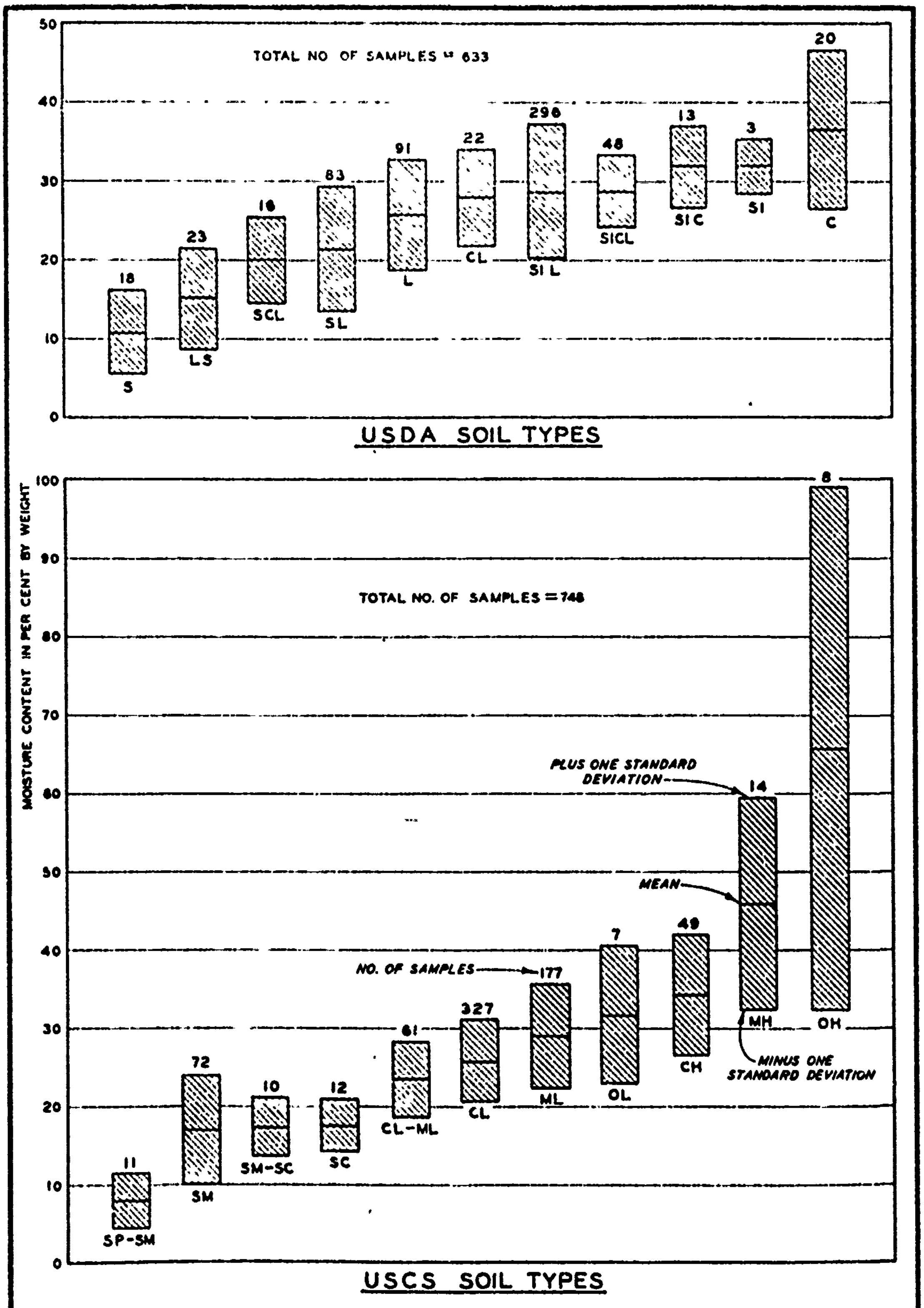
S	Sand
LS	Loamy sand
SL	Sandy loam
SCL	Sandy clay loam
SC	Sandy clay
L	Loam
SiL	Silty loam
Si	Silt
CL	Clay loam
SiCL	Silty clay loam
SiC	Silty clay
C	Clay
Pt	Peat

USCS Soil Types

GM	Silty gravel (> 12% fines)
GC	Clayey gravel (> 12% fines)
SP-SM	Poorly graded silty sand (5-12% fines)
SM	Silty sand (> 12% fines)
SM-SC	Silty-clayey sand (> 12% fines)
SC	Clayey sand (> 12% fines)
ML	Silt LL < 50
CL-ML	Silty clay
MH	Silt LL > 50
CL	Lean clay LL < 50
CH	Fat clay LL > 50
OL	Organic silt LL < 50
OH	Organic clay LL > 50
Pt	Peat

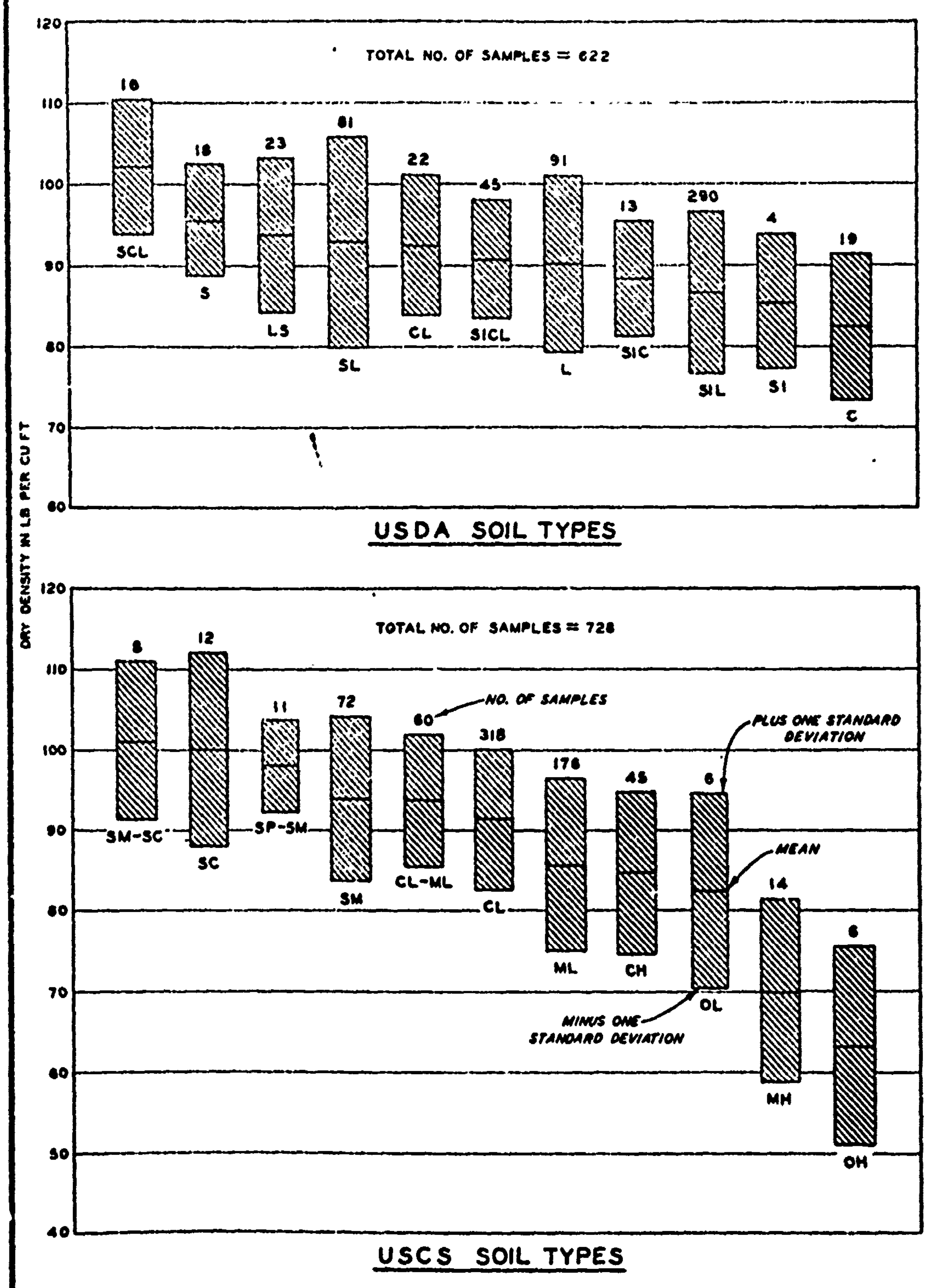
TRANSLATION OF CAPTIONS OF FIGURES 1-6

English		French
FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES	FIG. 1	TENEURS EN EAU MAXIMUM DU TERRAIN MOYENNES ET GAMMES
DENSITIES AT FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES	FIG. 2	DENSITÉS À DES TENEURS EN EAU MAXIMUM DU TERRAIN MOYENNES ET GAMMES
CONE INDEXES AT FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES	FIG. 3	INDICES DE CÔNE À DES TENEURS EN EAU MAXIMUM DU TERRAIN MOYENNES ET GAMMES
REMOLDING INDEXES AT FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES	FIG. 4	INDICES DE REMANIEMENT À DES TENEURS EN EAU MAXIMUM DU TERRAIN MOYENNES ET GAMMES
RATING CONE INDEXES AT FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES	FIG. 5	INDICES DE CÔNE REMANIÉS À DES TENEURS EN EAU MAXIMUM MOYENNES ET GAMMES
MEAN VALUES OF SOIL PROPERTIES AT FIELD MAXIMUM MOISTURE CONTENTS	FIG. 6	VALEURS MOYENNES DES PROPRIÉTÉS DU SOL À DES TENEURS EN EAU MAXIMUM DU TERRAIN



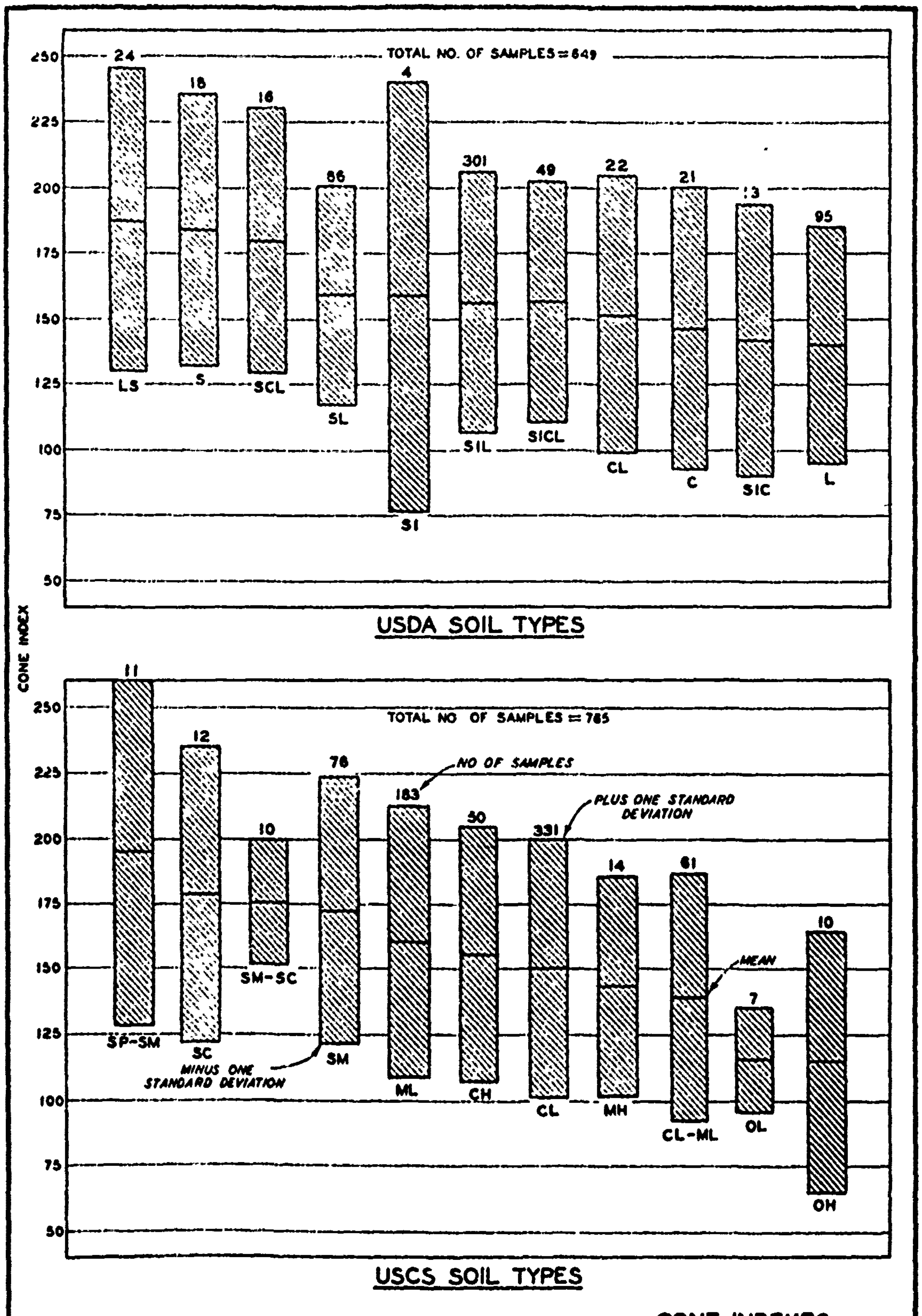
FIELD MAXIMUM
MOISTURE CONTENTS
MEANS AND RANGES

FIG. 1



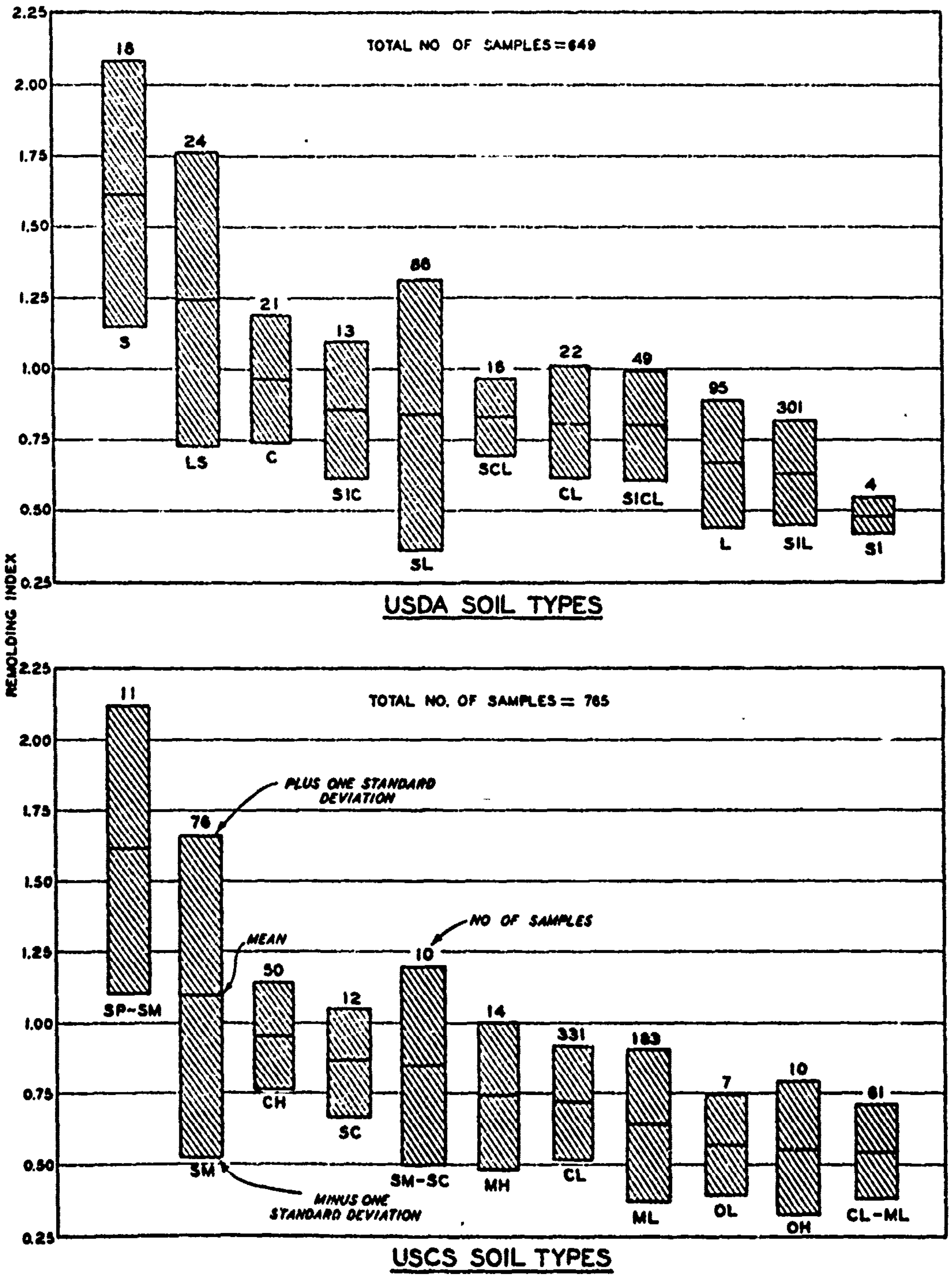
DENSITIES AT
FIELD MAXIMUM
MOISTURE CONTENTS
MEANS AND RANGES

FIG. 2



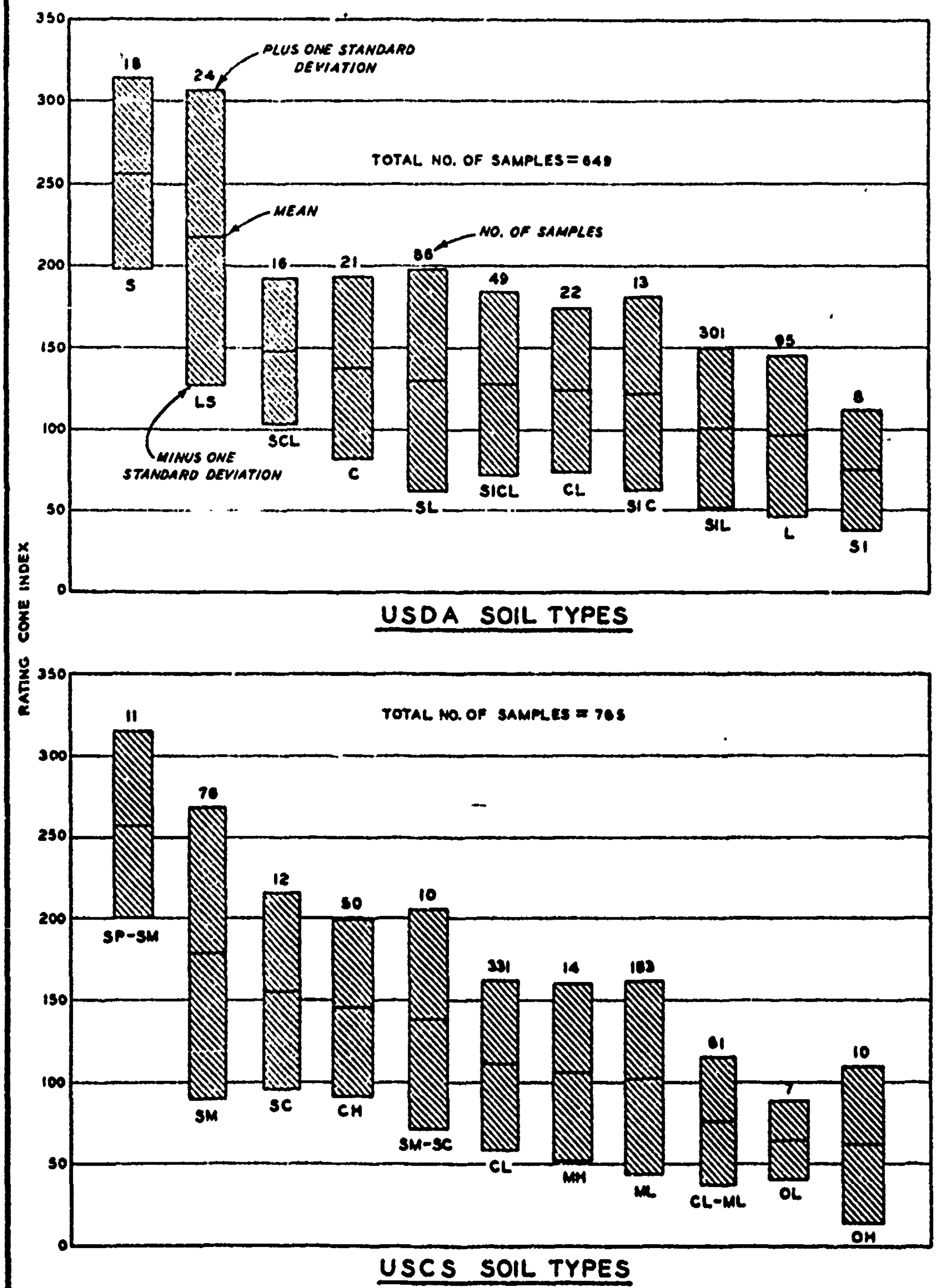
CONE INDEXES
AT FIELD MAXIMUM
MOISTURE CONTENTS
MEANS AND RANGES

FIG. 3



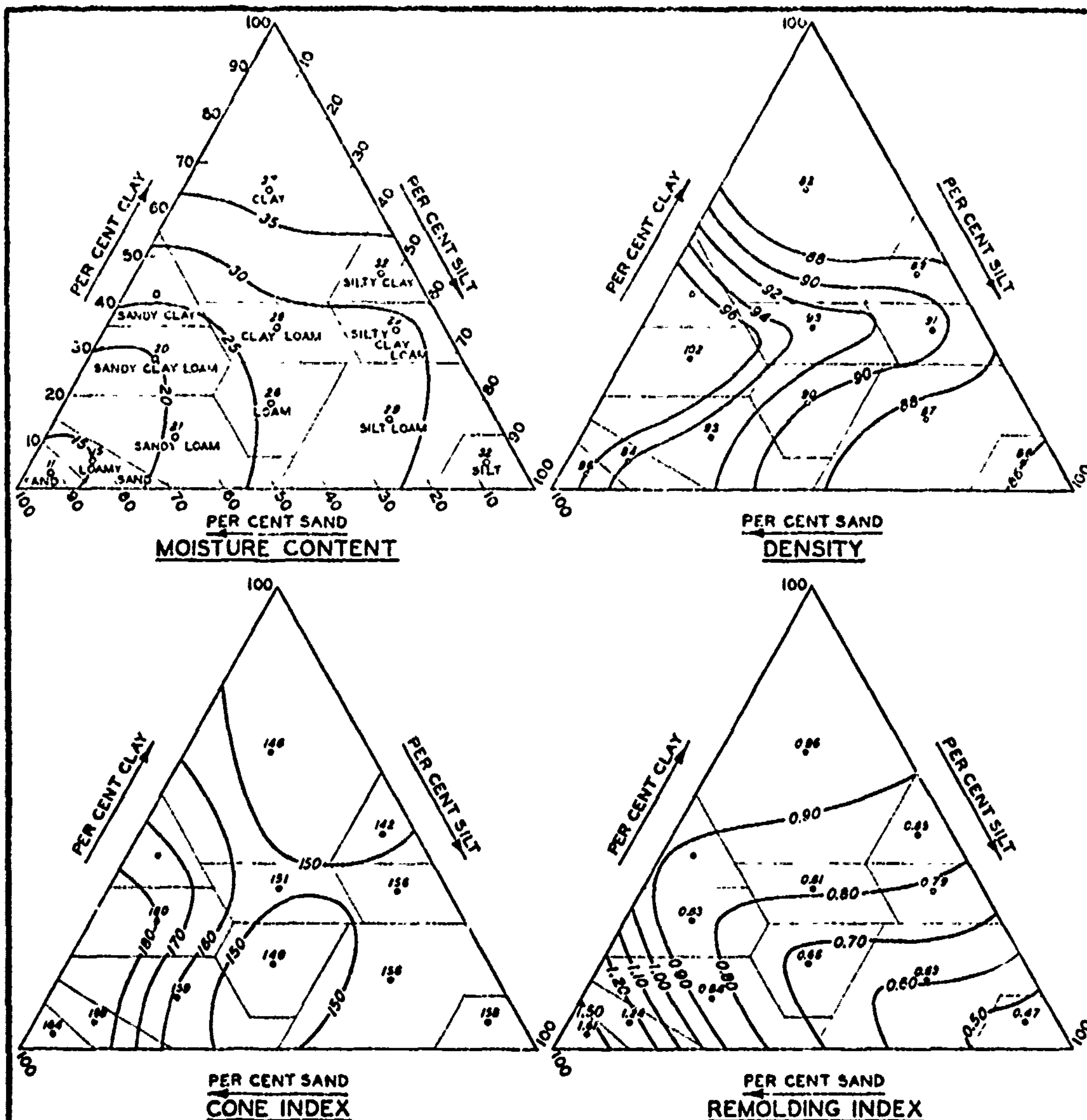
REMOLDING INDEXES AT FIELD MAXIMUM MOISTURE CONTENTS MEANS AND RANGES

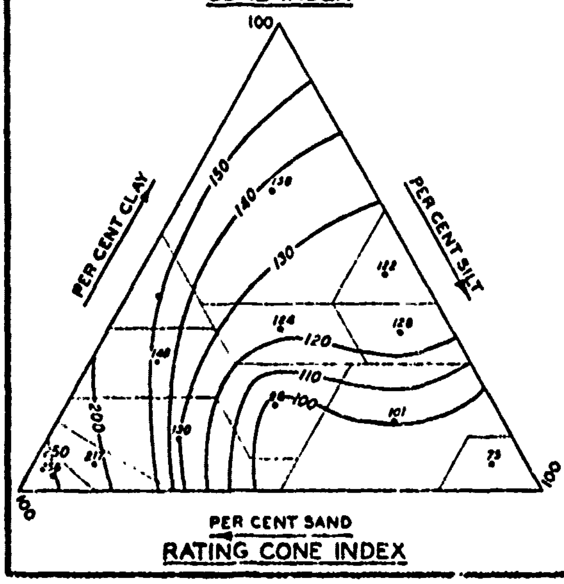
FIG. 4



RATING CONE INDEXES AT FIELD MAXIMUM MOISTURE CONTENTS
MEANS AND RANGES

FIG. 5





MEAN VALUES OF SOIL PROPERTIES AT FIELD MAXIMUM MOISTURE CONTENTS

FIG. 6

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